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research division

To: Mr. C. J. Bromley
Technical Superintendent
Bruce B NGS

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# STABILIZER PERFORMANCE DURING LOW FREQUENCY POWER OSCILLATIONS

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During load maneuvering on Bruce Unit 5 in mid-1987, low frequency power oscillations were detected. These oscillations seemed to occur at loads below 800 MW for any small disturbances on the unit, such as injecting a step change in the AVR reference point or taking one exciter out of service. Representatives from the generator/exciter manufacturer suspected the power system stabilizers on the unit as the cause. Dynamic performance tests showed conclusively that the cause is not related to the stabilizers or exciters.

## 1.0 BACKGROUND

In mid-1987, during load maneuvering on Bruce B unit 5, low frequency power oscillations were detected at loads below 800 MW whenever the unit was subjected to small disturbances. The turbo-generator manufacturer, Canadian General Electric, after some investigations of governor performance, blamed the power system stabilizers as the cause of the oscillations. Electrical Research was asked to verify the performance of the stabilizers and determine if indeed they were responsible for the oscillations. This was done during a site visit on September 18, 1987. During the same site visit, problems with spurious operations of the V/Hz limiter on the "B" exciter of unit 5 were investigated. Training was provided to station staff to allow them to conduct dynamic testing of the stabilizers and excitation systems on these units. Possible causes of apparent spurious failures in the B stabilizer on unit 8 were discussed with station staff.

On November 24$^{th}$ and 25$^{th}$ Research staff investigated the cause of an erratic operation of the stabilizer on exciter B of unit 5. Results are presented in this report.

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## 2.0 NATURE OF THE LOW FREQUENCY OSCILLATIONS

With the unit operating at loads below 800 MW, oscillations at 0.1 Hz in the output power were reported by station operators. Though these oscillations were damped, peak power swings of 50 MW were observed. Records obtained by station personnel show the damping to be very poor, with oscillations being sustained for more than ten cycles. Any minor disturbance was enough to set the oscillations in motion. These oscillations are unit-specific and not related to the 0.3 Hz power system oscillations receiving wide attention recently.

## 3.0 EFFECT OF STABILIZER PERFORMANCE ON THE OSCILLATIONS

With the unit loaded to 840 MW, the Delta-P-Omega stabilizers on unit 5 were checked completely to ensure correct initial performance. Measurements indicated that the stabilizers were performing as expected, and as measured when initially placed in service in December 1984. Figure 1 shows the responses obtained with the gain set at its normal value of 20 (pu $E_t$ ref/pu speed) and with a gain of zero. In performing this test the stabilizer gain was reduced to zero very slowly while small disturbances were applied. The performance of the unit was monitored closely to ensure that stability was maintained.

Following these initial tests, the load on the unit was reduced to 750 MW and the stabilizer tests repeated. Figure 2 shows the performance obtained with the stabilizer in service and Figure 3 shows the results with the stabilizer out of service. The maximum peak-to-peak power oscillation in figure 2 is 11 MW and over 40 MW in figure 3. **The overall conclusions reached on completion of these tests are that the stabilizer, instead of causing the power oscillations, actually contributes to reducing the amplitude of the swings.** The oscillations appear related to the turbine/steam governing system. Oscillations could be easily induced by applying disturbances of less than half a percent in the unit terminal voltage through the AVR, two or three times in a row.

## 4.0 STABILIZER DYNAMIC TEST PROCEDURE

Station personnel had prepared a preliminary test procedure based on the outline provided in section 8 of the power system stabilizer manual. That procedure was followed, with appropriate modifications where required, in demonstrating dynamic tests to station Control Maintenance staff. Research personnel tested the "A" stabilizer and Control Maintenance personnel performed the test on the "B" stabilizer of unit 5. The complete procedure, with modifications incorporated, is included as Appendix A of this report. A typical record obtained on unit 5 is included as Figure 1. Under normal conditions only the test with a gain setting of 20 would be performed.

## 5.0 RECALIBRATION OF VOLTS/Hz LIMITER CIRCUIT

It had been reported by unit 5 operators that the V/Hz controller on the "B" exciter of unit 5 would alarm (and likely limit) for no apparent reason. It was not established under what unit operating conditions these spurious operations occurred. As a first check the adjustment of the V/Hz circuit (Volts/Hertz Limit Card 189A6457G01) was checked. On this card, a dc signal proportional to generator terminal voltage is available on pin 34. When comparing the "A" and "B" cards, it was found that on the "B" card this signal was 8.38 volts and 8.12 volts on the "A" card, at a generator terminal voltage of 24.44 kV. The difference represents a terminal voltage error of 3.2%. If the unit is operated at a high terminal voltage, say 105%, the error could be enough to cause a spurious V/Hz limiter operation for small perturbations in system voltage

since the limiters are set to start acting at a nominal 109% of rated voltage. The gain on the "B" card was adjusted to obtain the same dc signal as on the "A" card. **During the next unit outage, the two V/Hz circuits should be fully calibrated.**

## 6.0 TEST PROCEDURE TO IDENTIFY OSCILLATIONS IN TERMINAL VOLTAGE

In a memo to Mr. G. Smith of Bruce B NGS from R. E. Beaulieu of Research, dated August 7, 1987, it was pointed out that the terminal voltage magnitude on unit 6, with the generator on open circuit, contained a 7.37 Hz component. No cause for this modulation of the amplitude was identified at that time though it was recommended that station staff investigate if the other units displayed the same behaviour. This oscillatory component is very small in amplitude, in the order of 0.015%, and does not seem to be a cause for concern, except for the fact that it is close in frequence to the first shaft torsional. This oscillation may be related to the problem encountered with the V/Hz circuit in the initial commissioning stages on unit 5. One reason to document this problem now is to have a written record, should a more serious probem occur in the future. Control maintenance personnel can use the terminal voltage transducer built into the stabilizer to carry out these measurements whenever a unit is on open circuit at rated voltage. The measurements can be done prior to synchronization without causing delays in the unit returning to service.

The Gould direct writing recorder owned by Control Maintenance can be used for these measurements. Calibration is as per the Dynamic Test Procedure, attached, except that on the terminal voltage channel, the maximum recorder amplifier gain is used. For the field voltage signal, the buck-off circuit of the amplifier can be used to record very small changes in the field voltage. Figure 4 shows the range of sensitivities required on each signal.

## 7.0 SPURIOUS FAILURES OF B STABILIZER ON UNIT 8

Unit 8 operators have reported that on a number of occasions, the "B" stabilizer on unit 8 failed and caused a transfer from AVR to MANUAL voltage control in the "B" exciter. Since these units are equipped with dual exciters, this transfer did not result in any system disturbances or unit limitations. Each time station staff investigated they found the stabilizer to be performing correctly with no signs of failures.

It was not possible to conduct any tests on this stabilizer. Possible causes for these spurious failures were discussed with station staff and they were requested to measure the two speed signals. [*A similar problem had been seen on unit 5, though only MVAR swings were detected. Our investigation at that time, reference memo to Mr. Jack Twolan from B. Pietrantonio, Jan. 15, 1985, showed that every now and then a speed signal pulse went missing. An intermittent connection in the speed cables was the cause of that problem.*]

In mid-October, Mr. Bruce Darcy reported that checks on the speed signals had not uncovered any abnormal conditions, though their measurements are not conclusive as far as intermittent faults are concerned. The next step is then to continuously monitor the power supply voltages and the four test points that indicate which failure mode is responsible for the apparent failures.

> Test point 4 on the Speed Signal Amplifier card is the output of the speed signal level detector. It is always at +15 Vdc unless the speed signal is lost.
>
> Test point 7 on the $P_e$ Amp and Mixing card is at +15 Vdc as long as the generator power is higher than 35% of full rated power.

Test point 6 on the Torsional Protection card is at +15 Vdc as long as there are no torsional oscillations above a certain threshold on the shaft (this situation should never be encountered).

Test point 3 on the Output card indicates an operation of the overall stabilizer self-monitoring circuits. This test point is at +15 Vdc under normal conditions.

A direct writing recorder, on very low speed, could be connected to the above signals and monitoring performed until the cause is identified. Research should be contacted if it is intended to follow through on this work. Prior to carrying out long term monitoring, however, station staff should verify that all the wiring associated with the stabilizer is intact, with no loose connections or damaged cables or leads.

## 8.0 STABILIZER PROBLEMS ON UNIT 5, EXCITER B

In the week of November 23 Research staff were asked to investigate the cause of an erratic behaviour by the stabilizer on exciter B of unit 5. Station personnel had disconnected the wire from the stabilizer output to the AVR input because they did not want an immediate trip to MANUAL if the B AVR was controlling and the stabilizer failed.

Our investigation showed the output of the speed input card to be very noisy, with a "chopped" 60 Hz component. This noise was amplified through the stabilizer gain. When Control Maintenance staff checked the signals on the stabilizer they found that the output of the shaft speed comparator on the TSEC card was sitting at about 8 volts. The reason for this signal was that the high ripple component on the speed signal was triggering the comparator, generating a square wave which averaged to 8 volts.

The ultimate cause of this problem was found to be a "high" resistance common on the power supply card. Thus, none of the stabilizer cards had a proper zero bus reference. The power supply module was repaired in the laboratory by replacing the POWERMATE module and returned to the station.

## 9.0 RECOMMENDATIONS

Power oscillations in the output of unit 5 at loads below 800 MW are not caused by the power system stabilizers. The exact cause of this problem should be identified and rectified as the consequences on overall power system stability could be serious.

The performance of the governor/steam supply system on the other three units, at reduced loads, should be verified to determine if this problem is specific to unit 5, as reported, or is a generic problem with the governor.

The Volts/Hz limiter on unit 5 should be fully calibrated during the unit outage to ensure correct operating limits. The manufacturer has already provided a procedure to perform this work.

Power system stabilizer performance must be verified on a regular basis, as per PSOD operating directives. The procedure to perform this work has now been demonstrated to station staff. The recorder available in the station, a Gould 4-channel direct writing, is ideal for this work.

Wiring connections associated with the "B" stabilizer on unit 8 should be checked. If no wiring problems are found then continuous monitoring of key test points will have to be conducted to determine the cause of spurious stabilizer failures.

Approved

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Submitted

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REB/reb

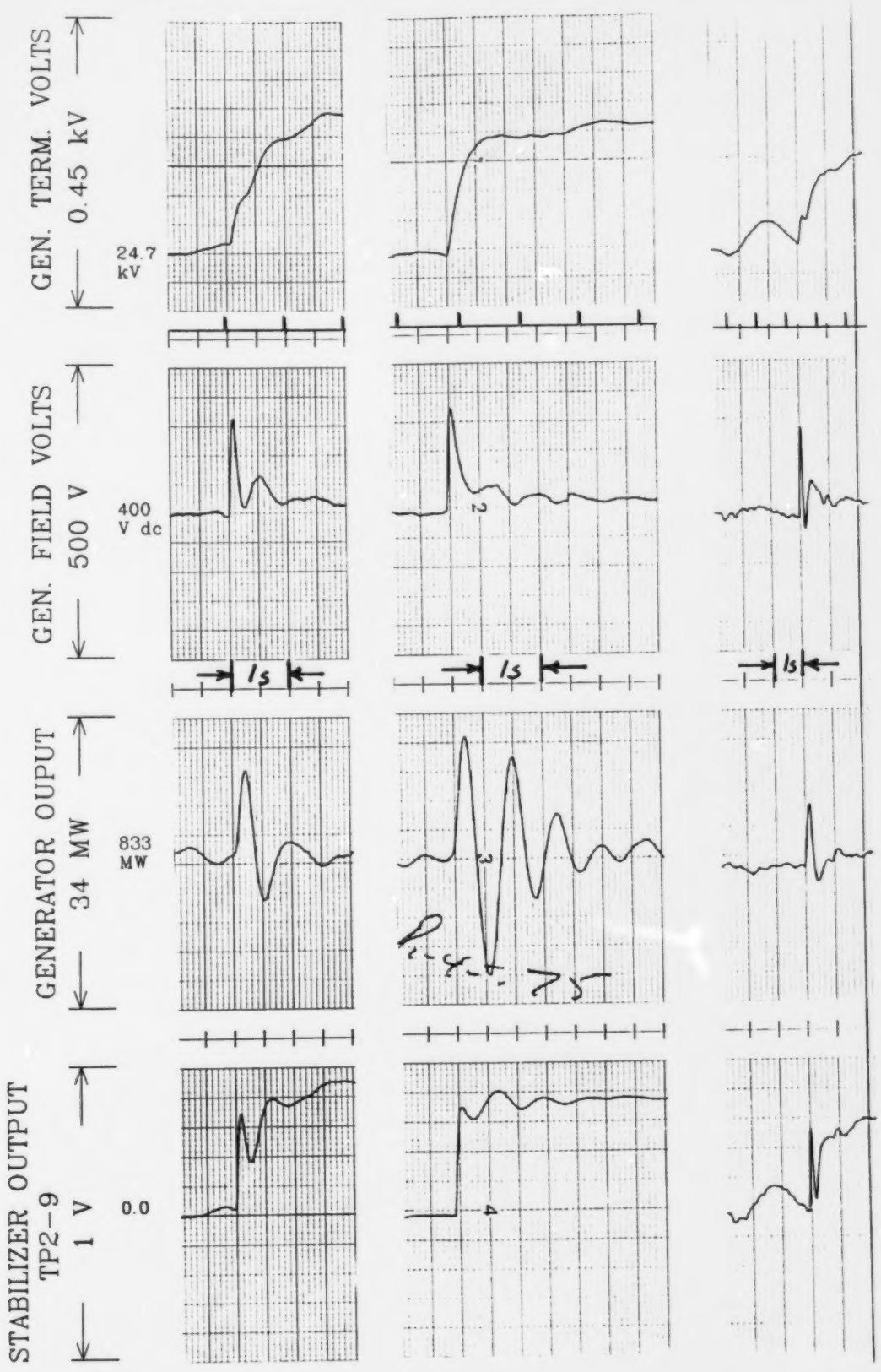
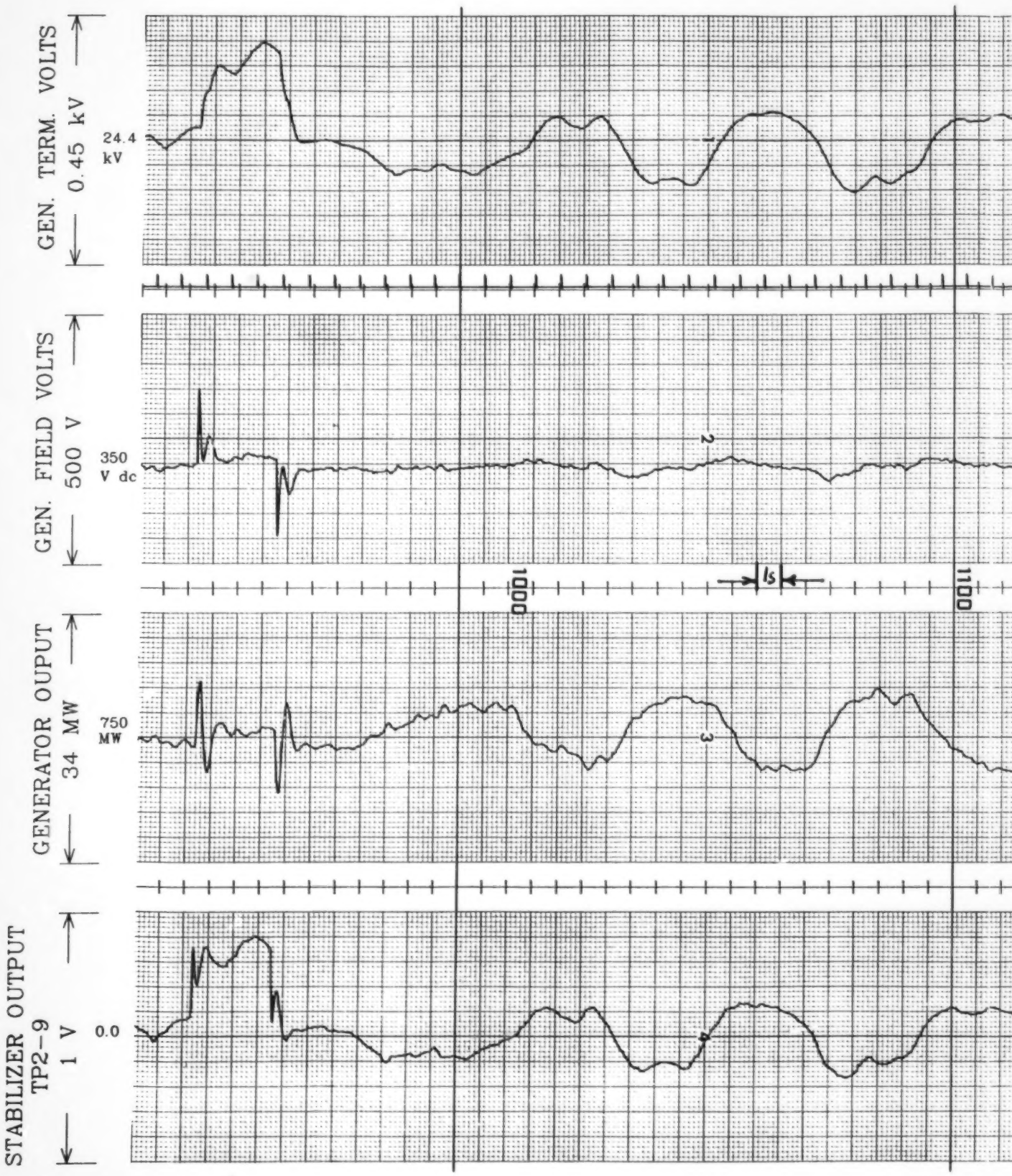



FIGURE 1 – BRUCE NGS UNIT 5
STABILIZER PERFORMANCE AT 833 MW

SEPT. 18, 1987




LAST OF A SERIES OF FOUR SMALL DISTURBANCES INTRODUCED THROUGH THE STABILIZER

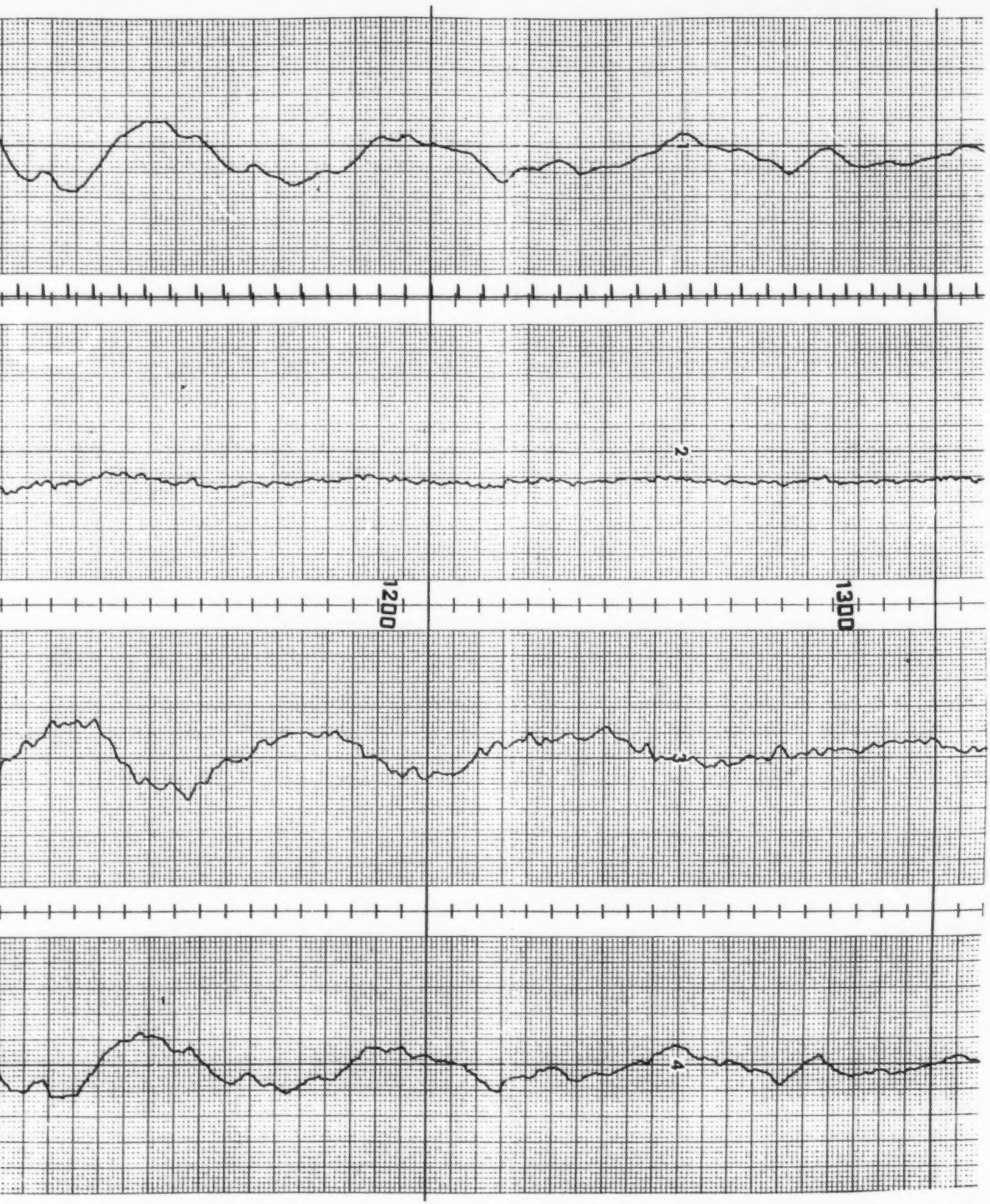
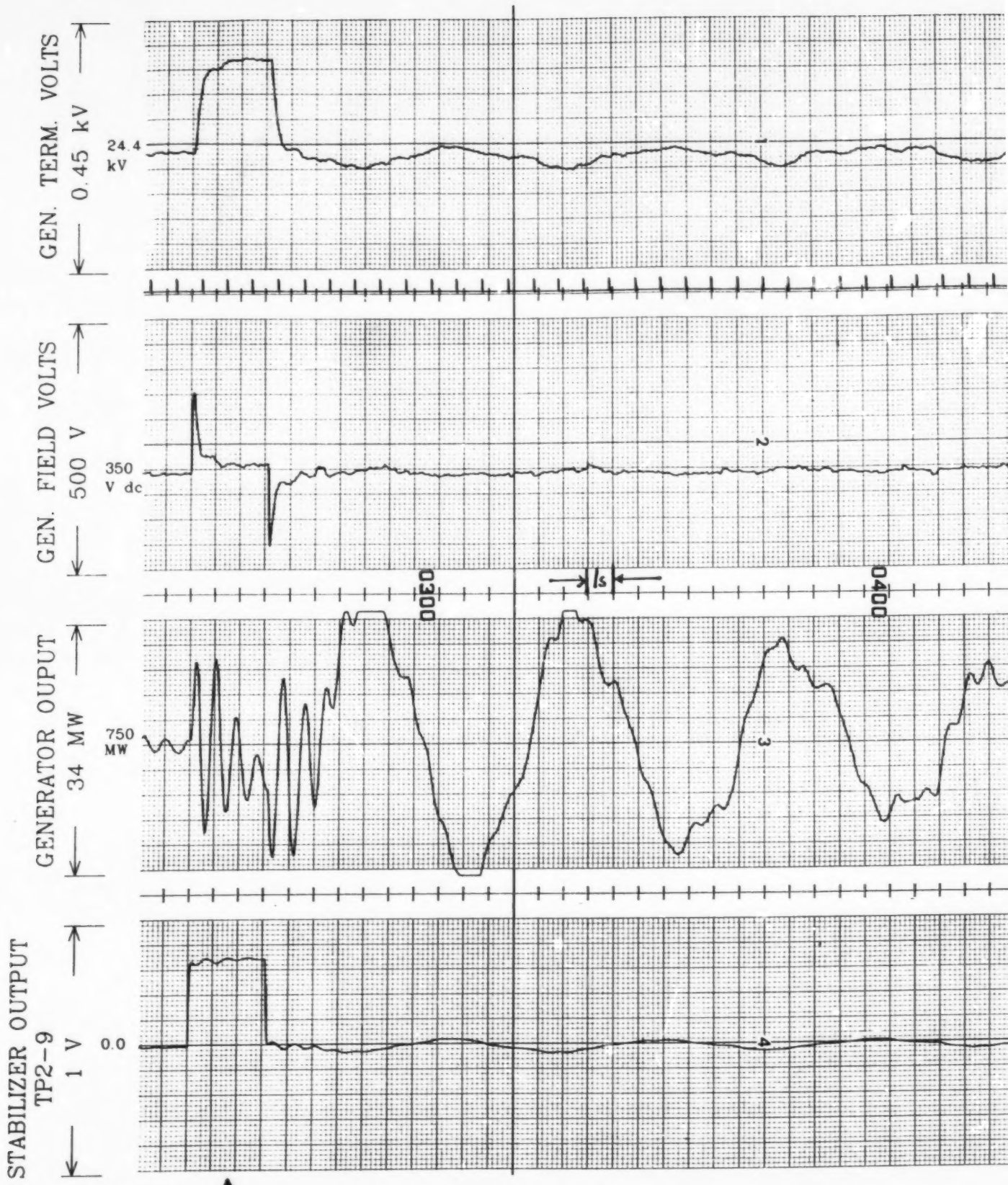



FIGURE 2 – BRUCE NGS UNIT 5
OSCILLATIONS WITH STABILIZER IN

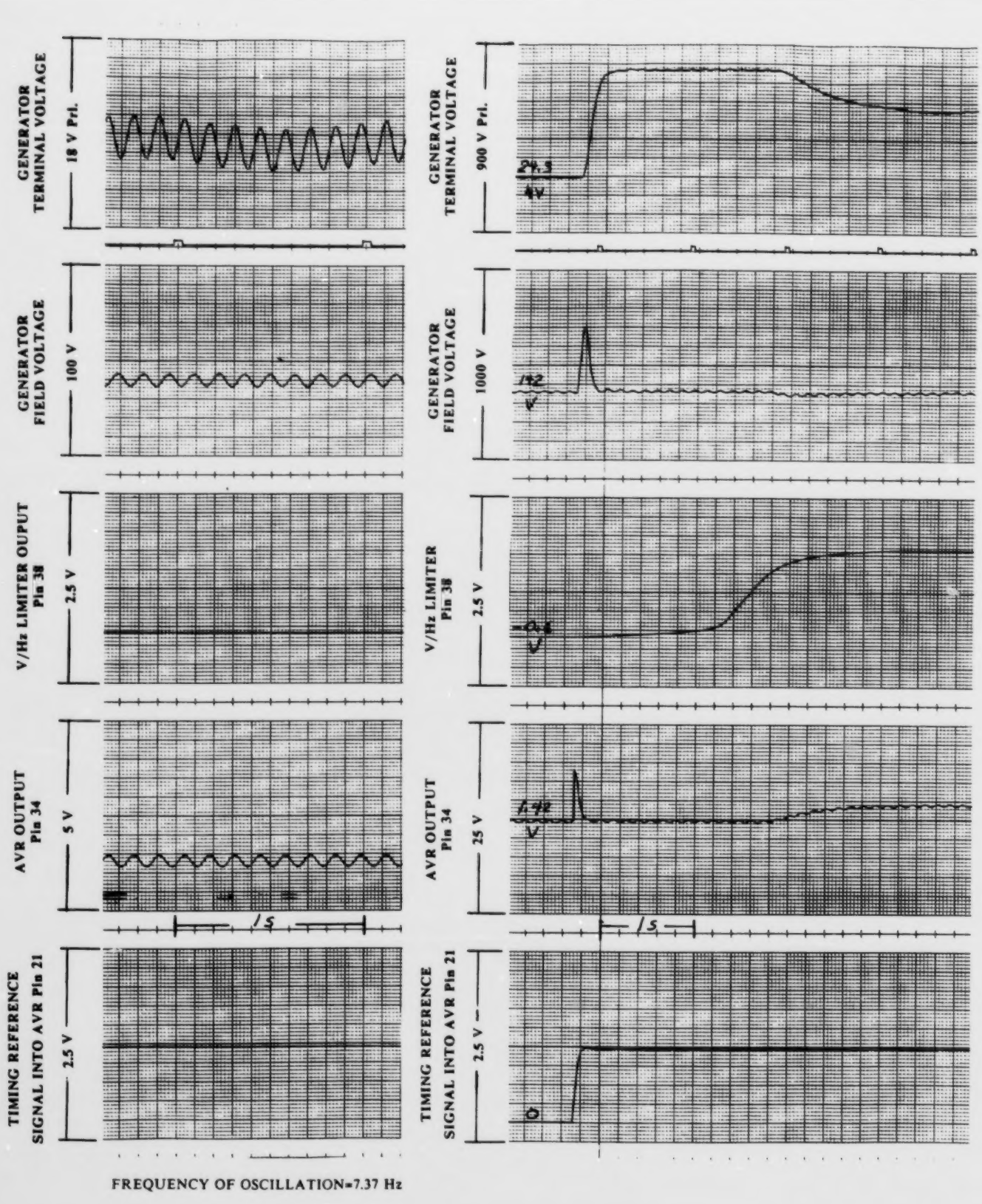
SEPT. 18, 1987




LAST OF A SERIES OF FOUR SMALL DISTURBANCES INTRODUCED THROUGH THE STABILIZER

FIGURE 3 – BRUCE NGS UNIT 5
OSCILLATIONS WITH STABILIZER OUT

SEPT. 18, 1987




FREQUENCY OF OSCILLATION=7.37 Hz

**FIGURE 4**
**LOW FREQUENCY VOLTAGE OSCILLATIONS**
**WITH THE UNIT ON OPEN CIRCUIT**
**BRUCE B - UNIT 6 - JULY 25/86**

# APPENDIX A

## A-1 Dynamic Testing of Exciter and Stabilizer Performance - Bruce B NGS

In 1980 a detailed test procedure was developed to verify the dynamic performance of power system stabilizers and excitation systems. The procedure is described in Research Report 80-294-K issued September 9, 1980, "Detailed Procedure For Dynamic Testing of Excitation Systems and Power System Stabilizers".

The procedure requires the use of a hot pen or ink recorder equipped with four medium gain channels. All other equipment to apply the step disturbance and interface the recording equipment to the signals is provided as an integral part of the stabilizer.

## A-2 Determination of a Testing Policy

Prior to any tests being performed, a general policy on when the tests are to be done must be established. This policy is the responsibility of station personnel in cooperation with System Control, System Performance and other concerned parties. The tests are to be performed at intervals specified by directives issued by the Power System Operations Division. The nature of the tests is such that they could be performed at almost any time without affecting the system.

## A-3 General Procedure

### 1.0 PURPOSE

The Dynamic Testing Procedure is designed to verify the dynamic performance of the power system stabilizer and excitation system.

### 2.0 REFERENCE

$\Delta P\omega$ Stabilizer manual and Research report 86-201-K.

### 3.0 EQUIPMENT

Gould Multichannel Direct Writing recorder (at least 4 traces)
Digital Multimeter

### 4.0 HAZARDS

The personnel designated to perform the tests should have some basic knowledge of the stabilizer and excitation system to appreciate the nature of the tests and the care to be exercised.

### 5.0 LOCATION

Main unit exciter.

## 6.0 ISOLATION

Testing must be done with the generator and exciter on line - no isolation.

## 7.0 PROCEDURE

### 7.1 Preliminary Work

The following work must be performed prior to connecting the recording equipment to the stabilizer:

(a) Coordinate the testing schedule with the unit operators. Testing must be done at a loading greater than 75% of rated power. Determine the appropriate time of day at which the tests are to be performed. Ensure that all groups which should be notified are aware that the tests will be performed. If contingency measures are to be taken, ensure that they have been taken.

(b) Through discussions with the unit/station operators and visual inspection of the excitation system and stabilizer, determine the apparent status of the system. Check for targets, blocking switches in incorrect positions, restrictions on the system, abnormal behaviour, tracking between regulators and any other signs which could indicate the health of the system. If everything is okay, testing may proceed. Tests must not proceed if there is an obvious fault or limitation on the system which could adversely affect the system.

(c) Calibrate the recorder with a known voltage source and check its overall operation. Check the quality of leads, possible damage to the amplifiers, noise in the channels, short circuits at the inputs, etc. Leads must be clearly identified to avoid connection errors.

(d) Set the recorder for the following values:

| | |
|---|---|
| Chart speed: | 10 mm/second |
| Channel #1, $\Delta E_t$: | 1 V Full Scale |
| Channel #2, $E_f$: | 5 V Full Scale |
| Channel #3, $\Delta P_e$: | 5 V Full Scale |
| Channel #4, $\Delta P\omega$ output: | 1 V Full Scale |

(e) Unit must be operating on AVR "A" and AVR "B" must be available.

(f) Perform the test on the AVR "A" stabilizer first.

### 7.2 Performing the Test

With the requirements of Section 7.1 satisfied, it is now possible to proceed with the test. **Ensure that the power supply switch on TEST 3 card is in the "ON" position.**

(a) The terminal voltage signal is measured on TP-$E_t$ with a floating dc voltmeter. This signal should be approximately 6.5 V and it should be related to the primary terminal voltage by obtaining $E_t$-primary from the unit operators:

TP-$E_t$ signal _____ V dc = _____ kV primary.

(b) The $E_t$ BIAS and RANGE potentiometers on Test 3 card are adjusted to produce a zero volt signal on TP-$\Delta E_t$. To adjust these two potentiometers, connect a voltmeter to TP-$\Delta E_t$. Set the ten-turn $E_t$ BIAS potentiometer to 5.0/10. Now, if the signal on TP-$\Delta E_t$ is positive, turn the RANGE potentiometer clockwise until the signal on the voltmeter is approximately zero. The BIAS potentiometer can then be used to fine-tune the biasing. Note that with a unit on line, the terminal voltage fluctuates constantly and the signal on TP-$\Delta E_t$ will have a small "noise" component.

With the application of a step disturbance, changes in $E_t$ are measured on TP-$\Delta E_t$ as per:

$$\Delta E_t \text{ in } \% = \frac{\text{TP-}\Delta E_t \text{ signal (V dc)}}{\text{TP-}E_t \text{ signal x } 20} \text{ x } 100\%$$

The factor of 20 in the denominator of the equation above is a gain on the isolator card. Refer to Figure A-1 for a better understanding of how the signals are derived from transducers and gains inside the stabilizer.

(c) The electrical power signal is calibrated in much the same way. The signal on TP-$P_e$ is measured and related to the existing loading on the unit. The signal on TP-$P_e$ should be:

$$\text{TP-}P_e \text{ signal} = \frac{\text{MW x } 10^6}{\text{CT x PT}} \text{ x } 0.1 \text{ x } 10^{-3} \text{ x } 31.9 = \frac{\text{MW x } 3190}{\text{CT x PT}} \text{ V dc}$$

At Bruce B NGS, the following ratios apply:
CT=4300/1
PT=200/1

TP-$P_e$ signal _____ (V dc) = _____ MW (existing loading)

(d) The $P_e$ BIAS and RANGE potentiometers on Test 3 card are adjusted to produce a zero volt signal on TP-$\Delta P_e$. Connect a voltmeter to TP-$\Delta P_e$. Set the ten-turn $P_e$ BIAS potentiometer to 5.0/10. Now if the signal on TP-$\Delta P_e$ is positive turn the RANGE potentiometer clockwise until the signal is approximately zero. The BIAS potentiometer can then be used to fine-tune the biasing.

With the application of a step disturbance $P_e$ will oscillate, and the peak of the oscillation, in megawatts, is calculated from:

$$\Delta P_e \text{ in MW} = \frac{\text{TP-}\Delta P_e \text{ signal (V peak)}}{\text{TP-}P_e \text{ signal x } 20 \text{ (V dc)}} \text{ x MW loading}$$

Again, the factor of 20 represents a gain in the isolator card. Refer to Figure A-1 for a better understanding of how the signals are derived from transducers and gains inside the stabilizer.

(e) The field voltage signal is measured on TP-$E_f$ and the stabilizer output signal on TP-$\Delta P\omega$. The field voltage signal on TP-$E_f$ should be:

$TP\text{-}E_f = 0.0071\ E_{f\text{-}pri}$ V dc

$TP\text{-}E_f =$ _____ V dc

Refer to Figure A-1 for a better understanding of how the signals are derived from transducers and gains inside the stabilizer.

The stabilizer signal should be less than ±100 mV when no disturbance is applied. Record the as-found stabilizer output:

STABILIZER OUTPUT_____mV ac or dc.

Acquire from the unit operator the main generator status:

MEGAWATTS_____

MEGAVARS_____

TERMINAL VOLTAGE_____

FIELD VOLTAGE_____

FIELD AMPS_____

(f) The recorder is then connected to the four test points: $\Delta E_t$, $E_f$, $\Delta P\omega$ OUTPUT and $\Delta P_e$. The zeros of $\Delta E_t$ and $\Delta P_e$ can be precisely adjusted to match the recorder zeros (no trace offset).

If the calibrations have been done properly, the sensitivities on the recorder will be approximately:

For $\Delta E_t$: 1 V dc = 0.9 V ac on PT secondary
For $E_f$: 1 V dc = 140 V dc on generator field
For $\Delta P_e$: 1 V dc = 13.5 MW
For $\Delta P\omega$: Direct

(g) A remote push button connected to the front jacks of TEST 1 card or the card-mounted PB can be used to apply the disturbance. The switch on this card is moved to the POS position and potentiometer P1 on this card is gradually increased until the disturbance, as measured by $\Delta E_t$, has the desired amplitude of approximately 0.5 to 1%. The recorder traces must be observed closely at all times to detect any undesirable effects. A change of 1% in $E_t$ is sufficient to determine the effectiveness of the excitation system and stabilizer. A good quality record at a recorder speed identical to previous records is taken and kept as the system "signature" for that particular day and particular system conditions.

7.3 Contact unit operator and have AVR control transferred from AVR "A" to AVR "B".

7.4 Perform the test on the "B" $\Delta P\omega$ stabilizer (AVR "B" controlling), starting at item 7.2.

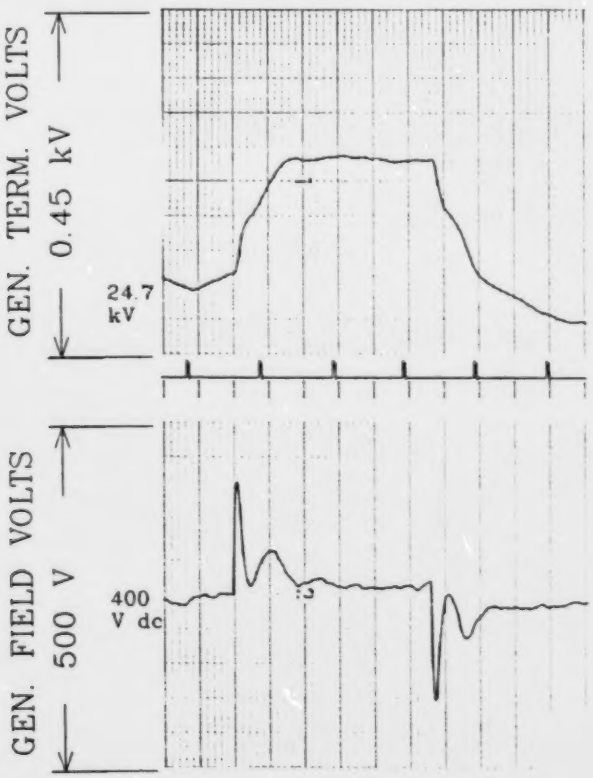
7.5 On completion of item 7.2, disconnect all test equipment from stabilizers and exciter. Ensure switch on TEST 1 cards in both stabilizers is OFF and P1 is at 0.0.

7.6 Contact unit operator and have AVR control transferred from AVR "B" to AVR "A".

7.7 This completes the dynamic testing on the stabilizers.

7.8 Measurement of Voltage Regulator Loop Gain

The voltage regulator loop gain of static exciters with no transient gain reduction (most exciters equipped with stabilizers) can be measured directly from the test record obtained by scaling the terminal voltage and field voltage traces. This technique produces results which, though not perfectly accurate, are valid for evaluating the performance of the excitation system. The technique to measure the gain from records is illustrated below. Assume that the record taken shows $E_t$ and $E_f$ to behave as shown in sketch #1.




Sketch #1
Measurement of Voltage Regulator Loop Gain

The terminal voltage steady-state value is shown on the record as 24.7 kV and the full scale sensitivity is 0.45 kV = 50 divisions. When the disturbance is applied, $E_t$ changes by 18 divisions (measurement is taken after $E_t$ has stabilized at its new value) or 18/50 x 0.45 kV = 0.162 kV. In per unit (pu) of rated $E_t$, and assuming a rating of 24 kV,

$$\Delta E_t \text{ (pu)} \frac{0.162}{24} = 0.00675 \text{ pu}$$

The field voltage trace shows a steady-state value of 400 V, a full scale sensitivity of 500 V = 50 divisions and a change in $E_f$ of:

16.5 divisions = 16.5/50 x 500 = 165 V

For this particular machine the base field voltage (field voltage required to produce rated terminal voltage on open circuit on the air gap line with rotor at 100°C) is 151.5 V. The pu change in $E_f$ is:

$$\Delta E_f \text{ (pu)} = \frac{165}{151.5} = 1.09$$

The regulator loop gain is defined as:

$$\text{Gain} = \frac{\Delta E_f \text{ in pu}}{\Delta E_t \text{ in pu}}$$

For the example above,

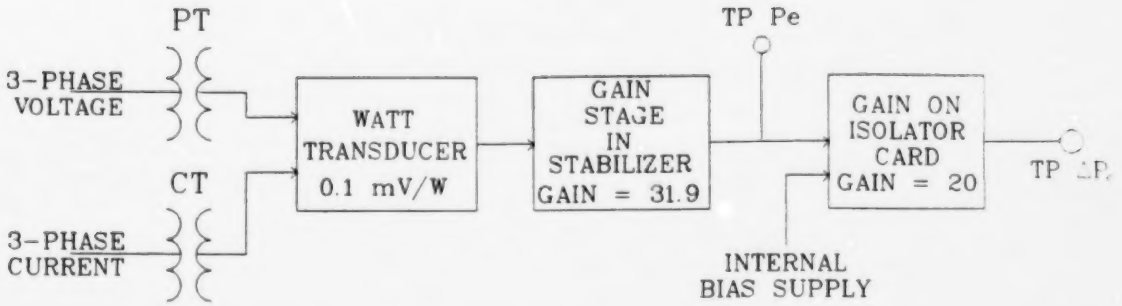
$$G = \frac{1.09}{0.00675} = 161$$

The rated terminal voltage of each generator is available at the station and the base field voltage is available from the unit open circuit saturation curves supplied by the manufacturers.

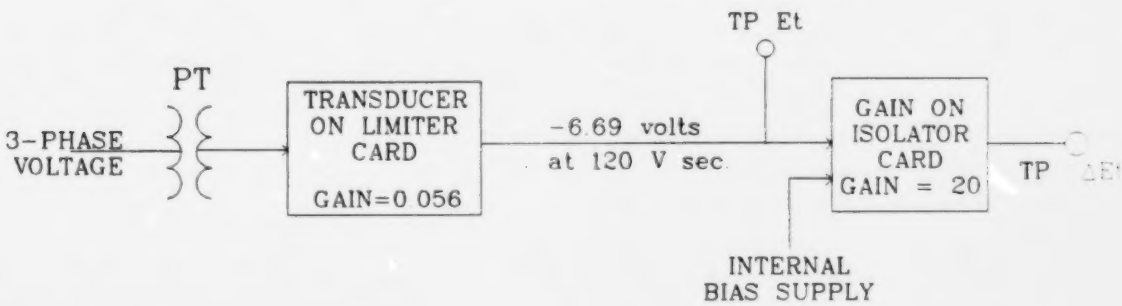
The gain measurement must be done with a disturbance of 1% or less so as not to force the field voltage to ceiling. Otherwise, if $E_f$ goes to ceiling the gain measurement will be in error, with the measured gain appearing smaller than it actually is.

Gain at Bruce NGS B is approximately 200. The measured value obtained during dynamic tests is always lower due to the filtering in the field voltage signal.

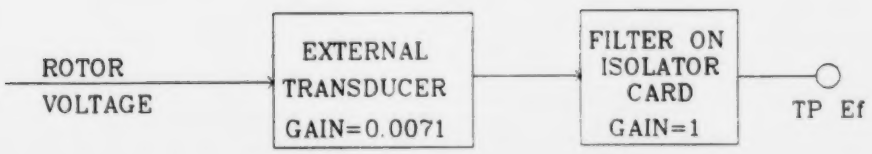
7.9 The recorder traces showing all pertinent information including the calculated gain figures are filed in the "Exciter Dynamic Stability Tests" binder found on the library shelves.




(a) CIRCUIT TO OBTAIN GENERATOR POWER




(b) CIRCUIT TO OBTAIN TERMINAL VOLTAGE




(c) CIRCUIT TO OBTAIN FIELD VOLTAGE

FIGURE A-1
SIGNAL MEASURING CIRCUITS